Possible Detectors for the Off-axis Experimet at NuMI

- Requirements/general aspects of ν_e detection
- Backgrounds and Detector Issues
- Detector Possibilities:
- Imaging calorimeters:
  - Low Z absorber + RPC
  - Modular detectors
  - Water + Liquid Scintillator
  - Liquid Argon TPC
  - Comments on Water Cherenkovs

Adam Para, Fermilab

'NuMI Off-Axis'

UCL, September 16, 2002

Receipe for an ν_e Appearance Experiment

J. Hylen

- Large neutrino flux in a signal region
- Minimize background (no neutrinos outside the signel region, small ν_e component of the beam)
- Good detector (efficiency, rejection against background)
- Large detector

Lucky coincidences:

- distance to Soudan = 735 km, Δm^2=0.025-0.035 eV^2

$$\frac{1.27\Delta m^2 L}{E} = \frac{\pi}{2} \quad \Rightarrow \quad E = \frac{2.54\Delta m^2 L}{\pi} \approx 1.6 - 2.2\ GeV$$

- Below the tau threshold! (BR(τ->e)=17%)

Beam-Detector Interactions

- Optimizing beam can improve signal
- Optimizing beam can reduce NC backgrounds
- Optimizing beam can reduce intrinsic ν_e background
  - Easier experimental challenge, simpler detectors
- # of events ~ proton intensity x detector mass
  - Split the money to maximize the product, rather than individual components

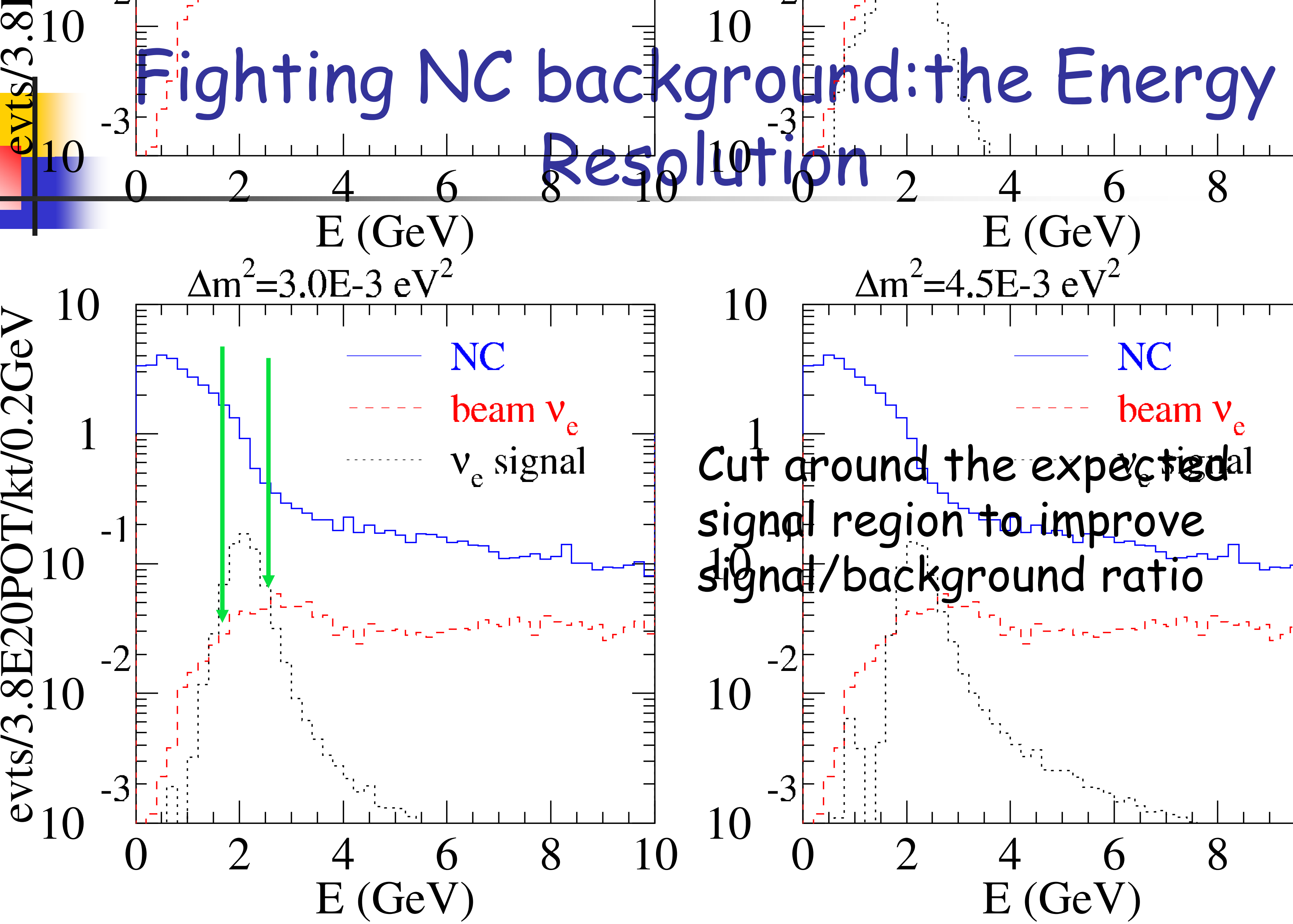
ν_e Appearance Experiment: a Primer

$$P = \frac{\#\,of\ \nu_e\ cand. - \varepsilon \nu_e^{beam} - \eta NC}{\varepsilon \int dE\,\Phi_\nu(E)\,\sigma_\nu^{CC}(E)\,P_{\nu_\mu \to \nu_e}(E, 100\%)}$$

$$P_{90\%CL}^{sens} = \frac{1.28\sqrt{\varepsilon \nu_e^{beam} + \eta NC}}{\varepsilon \int dE\,\Phi_\nu(E)\,\sigma_\nu^{CC}(E)\,P_{\nu_\mu \to \nu_e}(E, 100\%)}$$

- Know your expected flux
- Know the beam contamination
- Know the NC background*rejection power (Note: need to beat it down to the level of ne component of the beam only)
- Know the electron ID efficiency

Fighting NC background: the Energy Resolution



Cut around the expected signal region to improve signal/background ratio

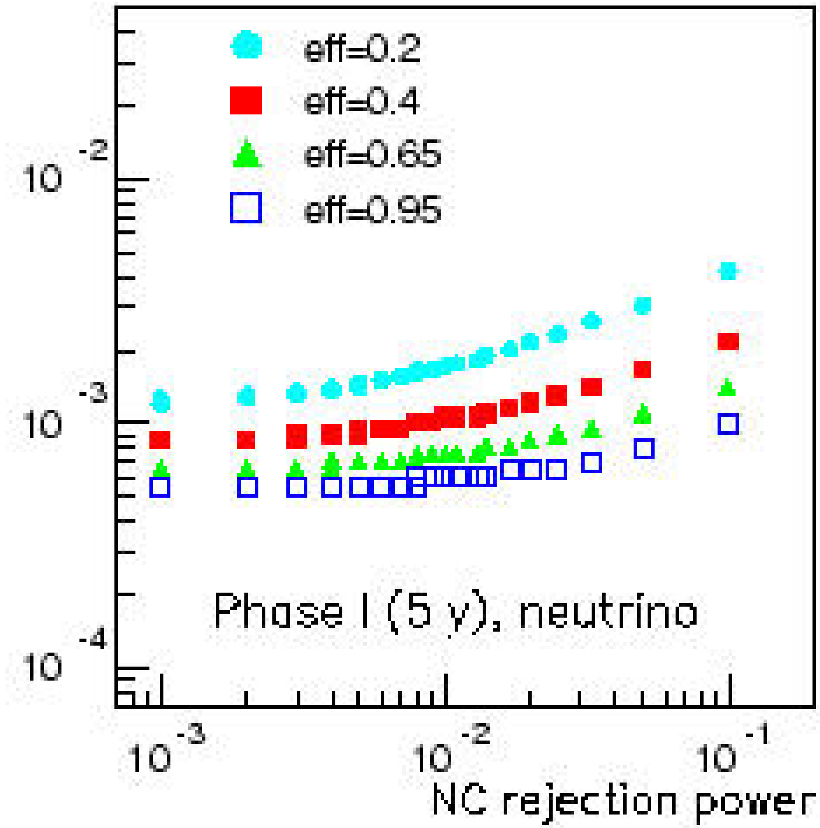
M. Messier, Harvard U.

Sensitivity dependence on ν_e efficiency and NC rejection

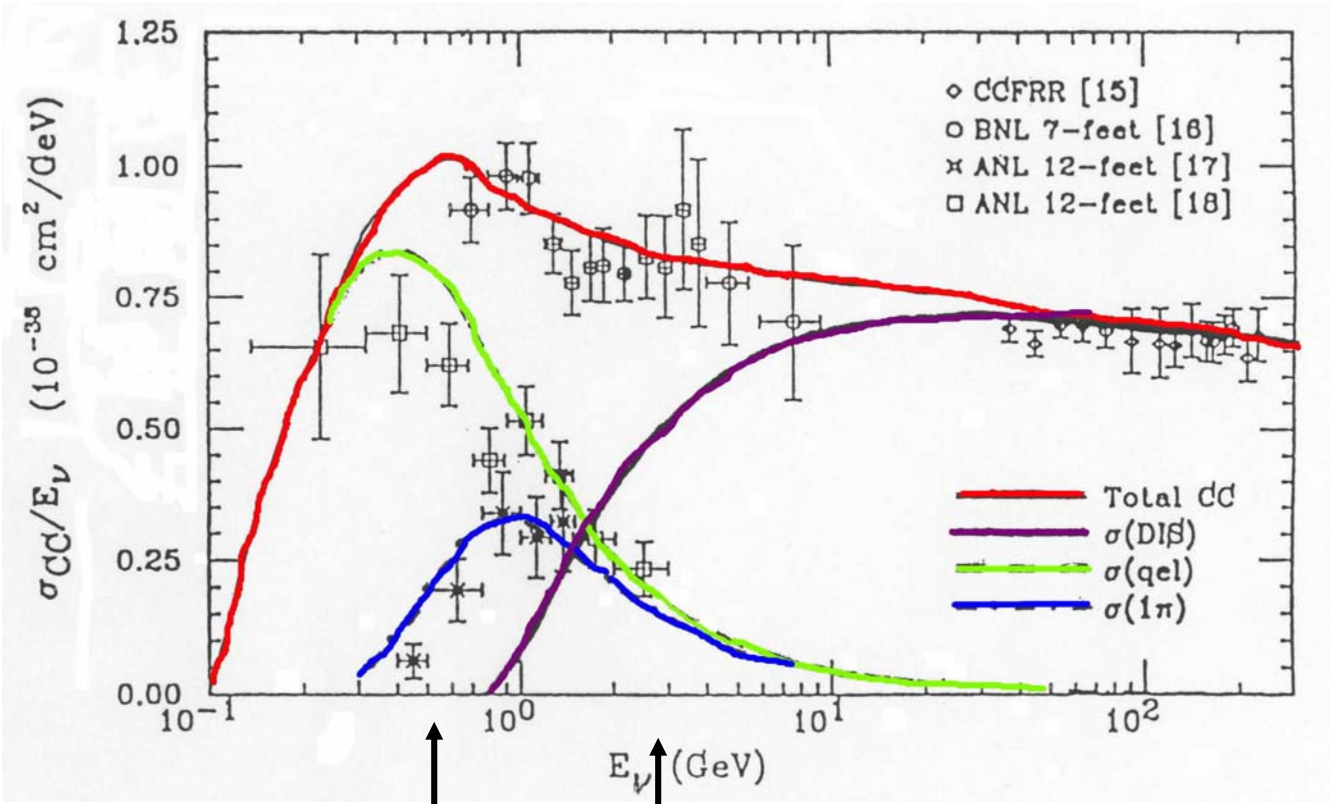
Major improvement of sensitivity by improving ID efficiency up to ~50%

Factor of ~ 100 rejection (attainable) power against NC sufficient

NC background not a major source of the error, but a <u>near detector</u> probably desirable to measure it



Neutrino Cross Sections

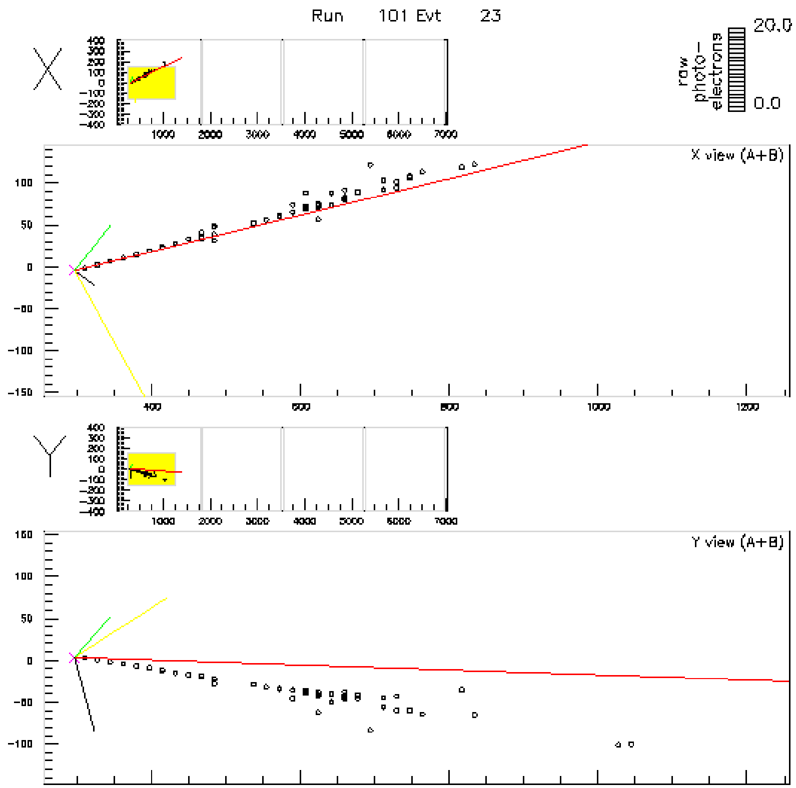


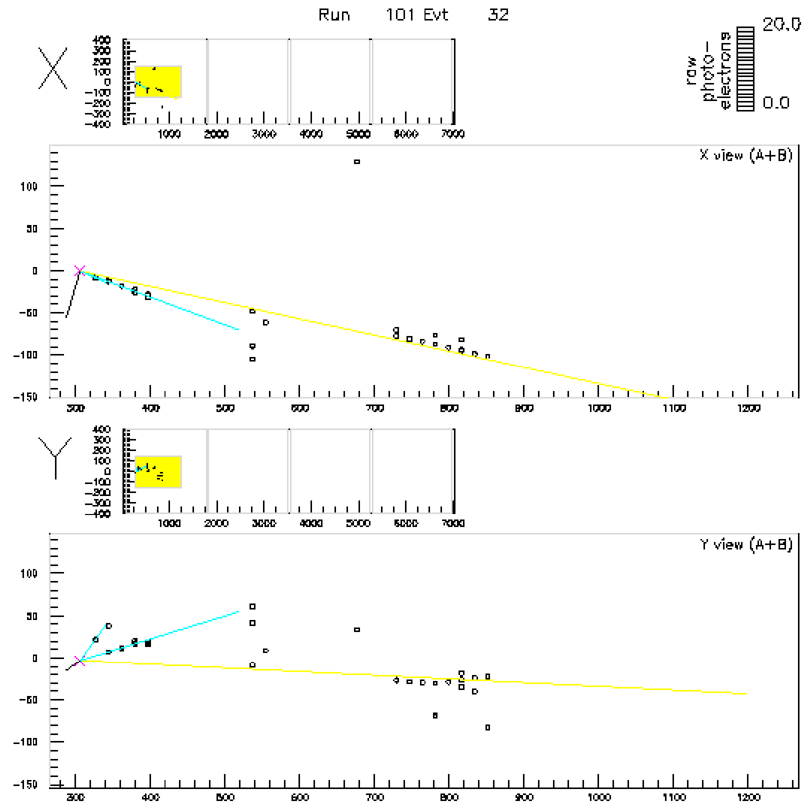
N+lepton

N+l+π

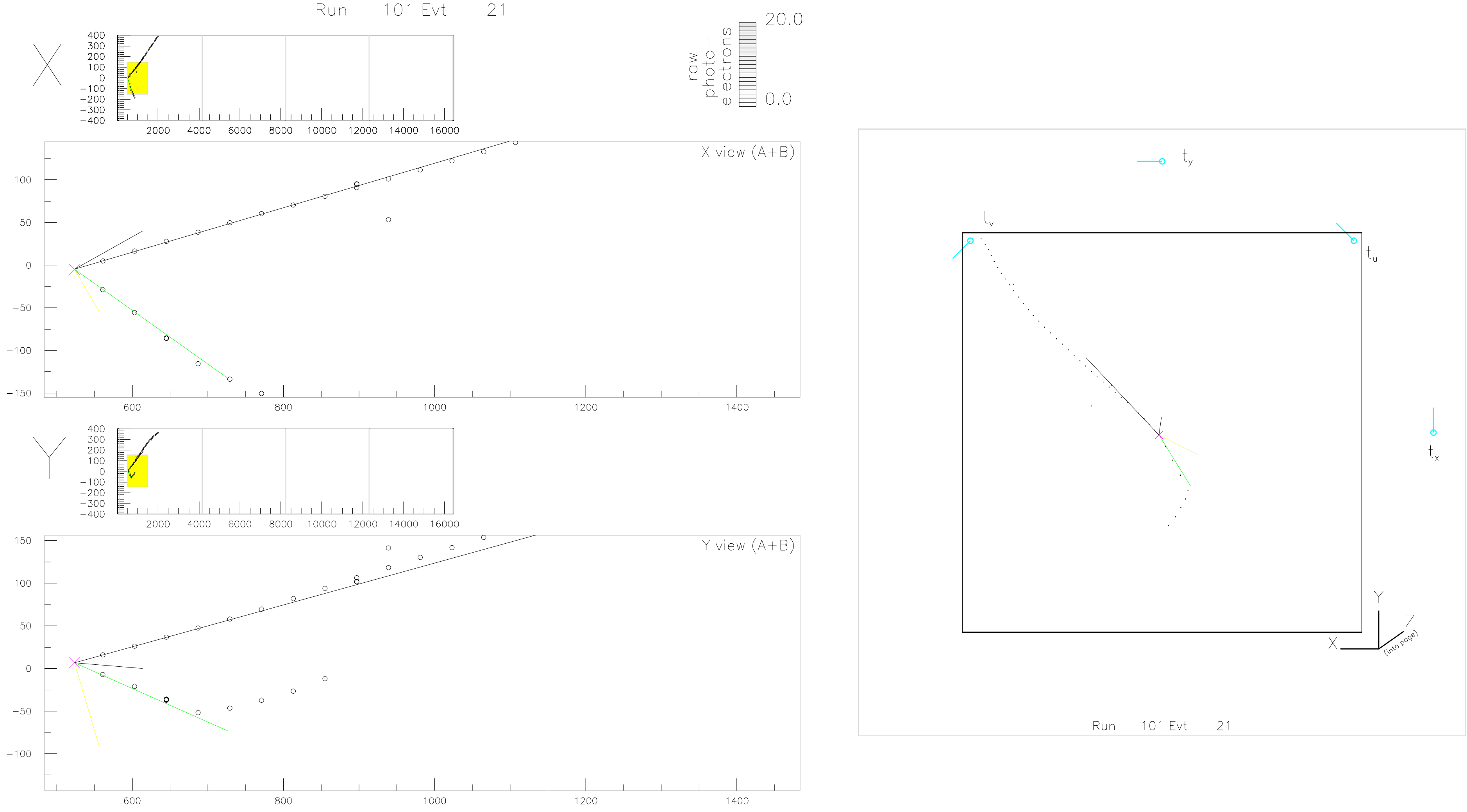
Many particles

~ 2 GeV: CC ν_e / NC interactions

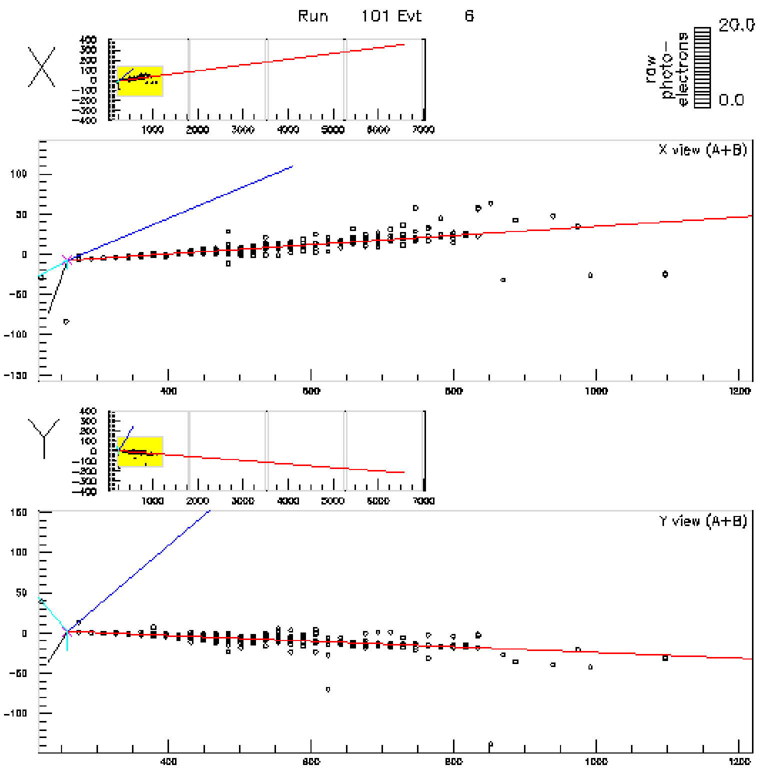


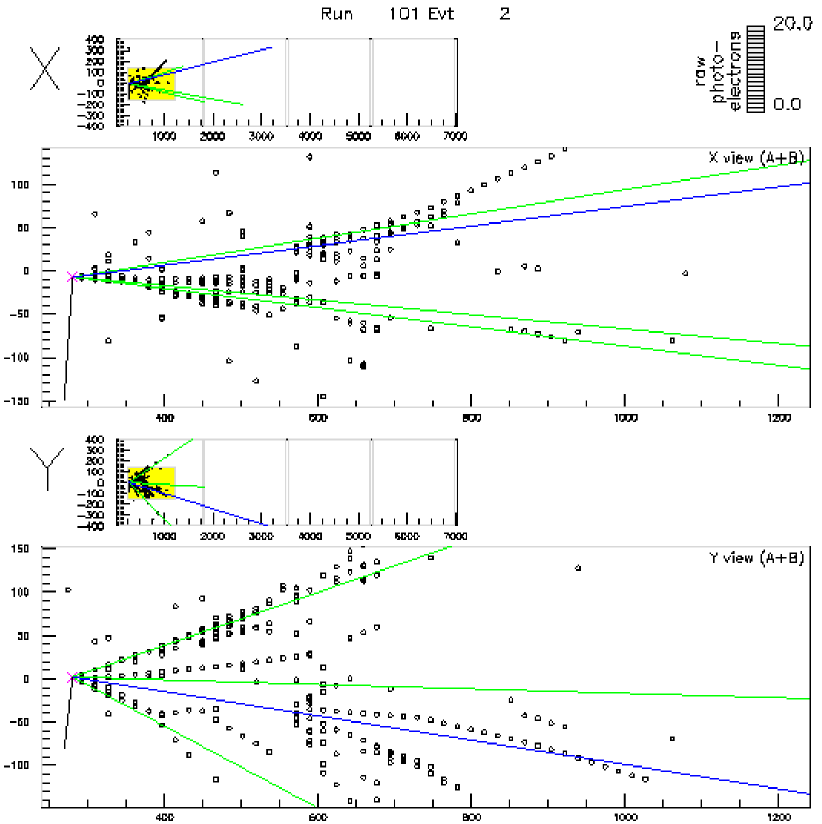


~ 2 GeV: ν_μ CC interaction

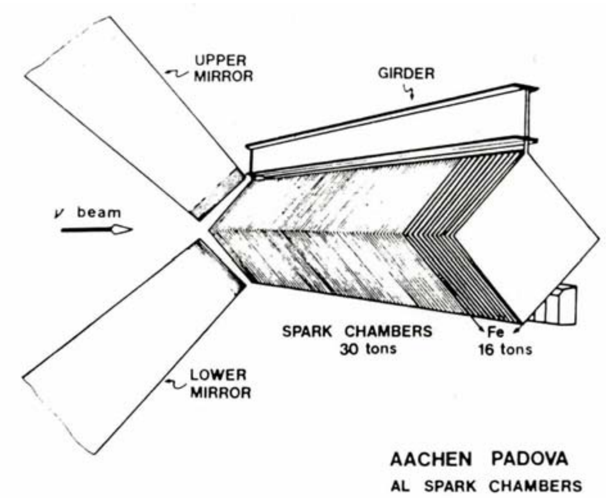


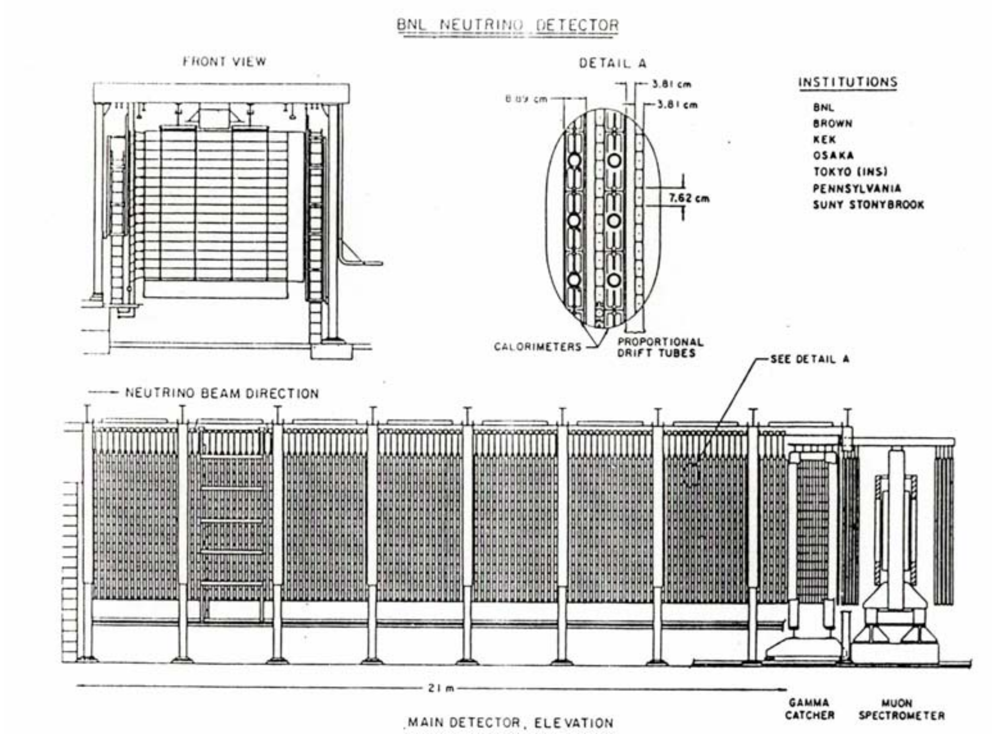
~ 7 GeV: CC ν_e / NC interactions





NC/ ν_e /π^0 detectors





CHARM II (ν_μe scattering)

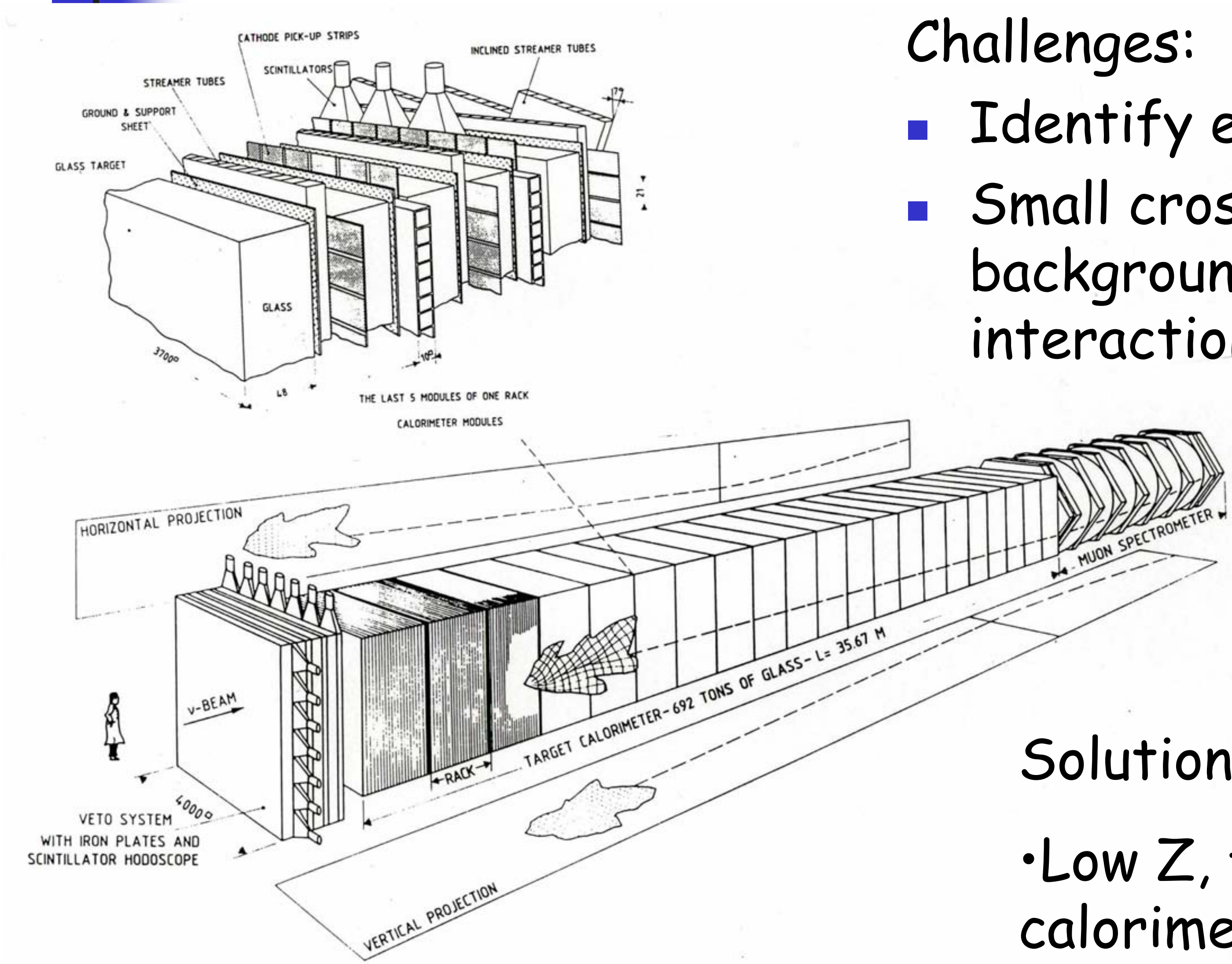


Fig. 2. Overview of the CHARM II detector.

Challenges:

- Identify electrons
- Small cross section, large background from NC interactions

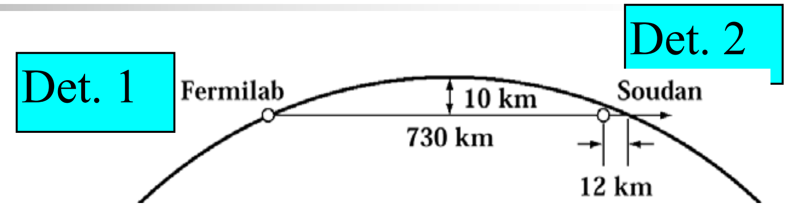
Solution:

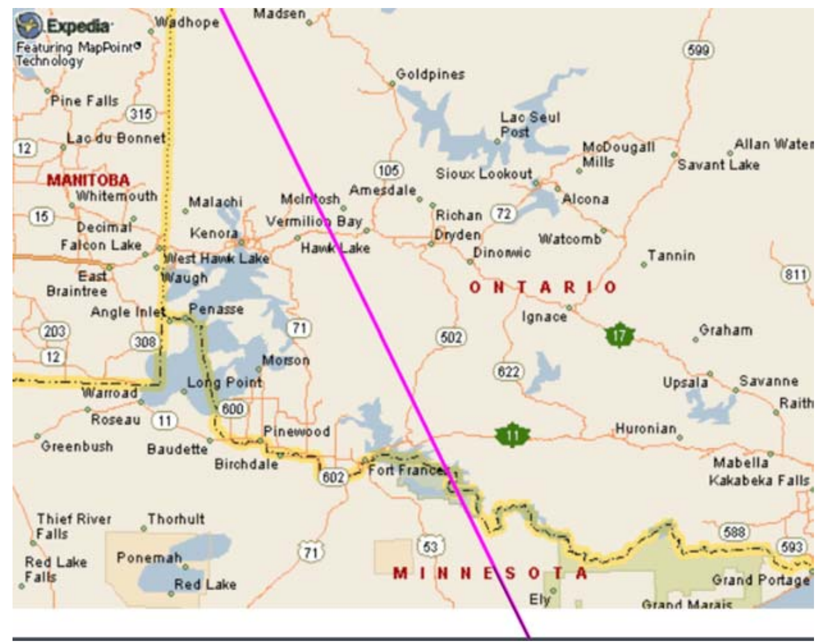
•Low Z, fine grained calorimeter

NuMI Off-axis Detector

- Different detector possibilities are currently being studied
- The goal is an eventual 20 kt fiducial volume detector
- The possibilities are:
  - Low Z target with RPC's, drift tubes or scintillator
  - Liquid Argon (a large version of ICARUS)
  - Water Cherenkov counter

NuMI Beam: on and off-axis





- Large selection of sites, baselines, beam energies
- Physcis/results driven experiment optimization

Detector(s) Challenge

- Surface (or light overburden)
  - High rate of cosmic μ's
  - Cosmic-induced neutrons
- But:
  - Duty cycle 0.5×10^{-5}
  - Known direction
  - Observed energy > 1 GeV

Principal focus: electron neutrinos identification

• Good sampling (in terms of radiation/Moliere length)

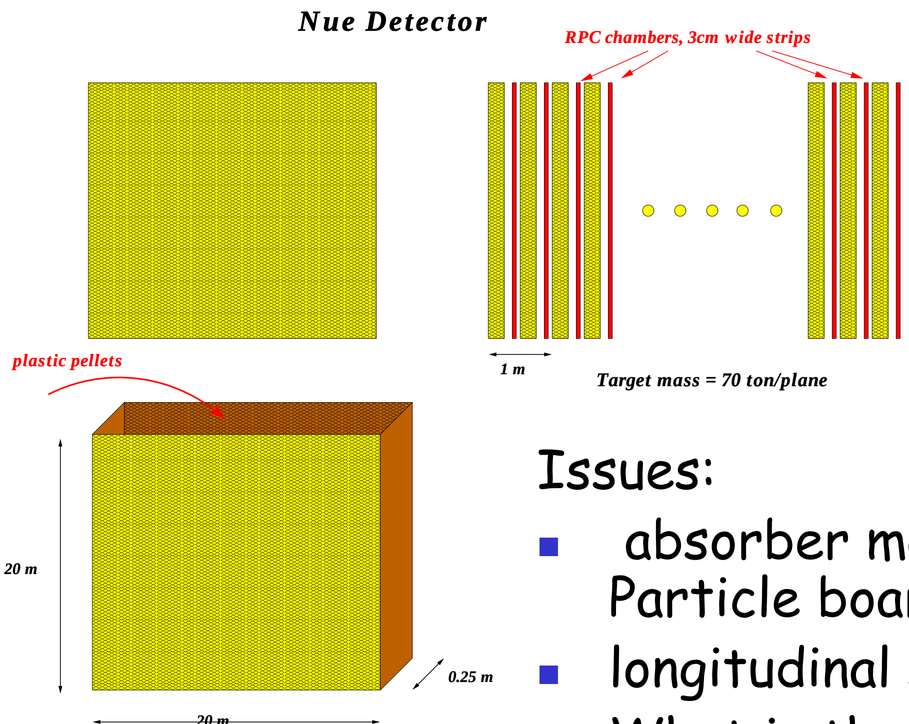
Large mass:

• maximize mass/radiation length

• cheap

An example of a possible detector

Low Z tracking calorimeter



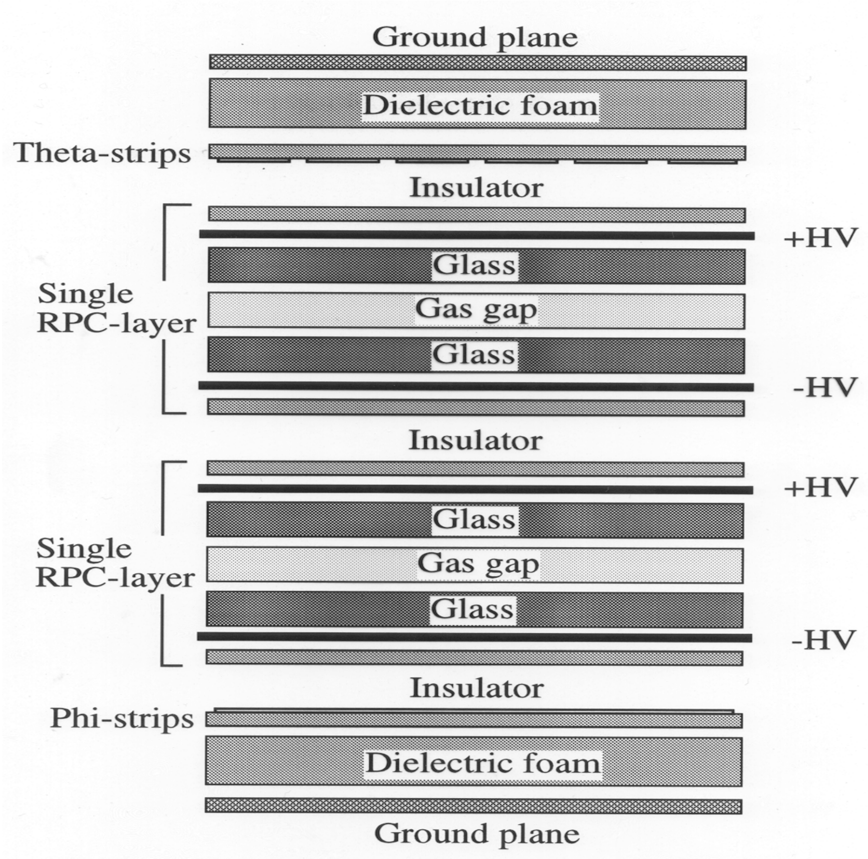
NuMI off-axis detector workshop: January 2003

Issues:

- absorber material (plastic? Water? Particle board?)
- longitudinal sampling (ΔX_0)?
- What is the detector technology (RPC? Scintillator? Drift tubes?)
- Transverse segmentation (e/π^0)
- Surface detector: cosmic ray background? time resolution?
- . . .

Resistive Plate Counters (Virginia Tech, BELLE)

Glass electrodes are used to apply an electric field of ~4kV/mm across a 2mm gap. The gap has a mixture of argon,isobutane and HFC123a gas. An ionizing particle initiates a discharge which capacitively induces a signal on external pickup strips.

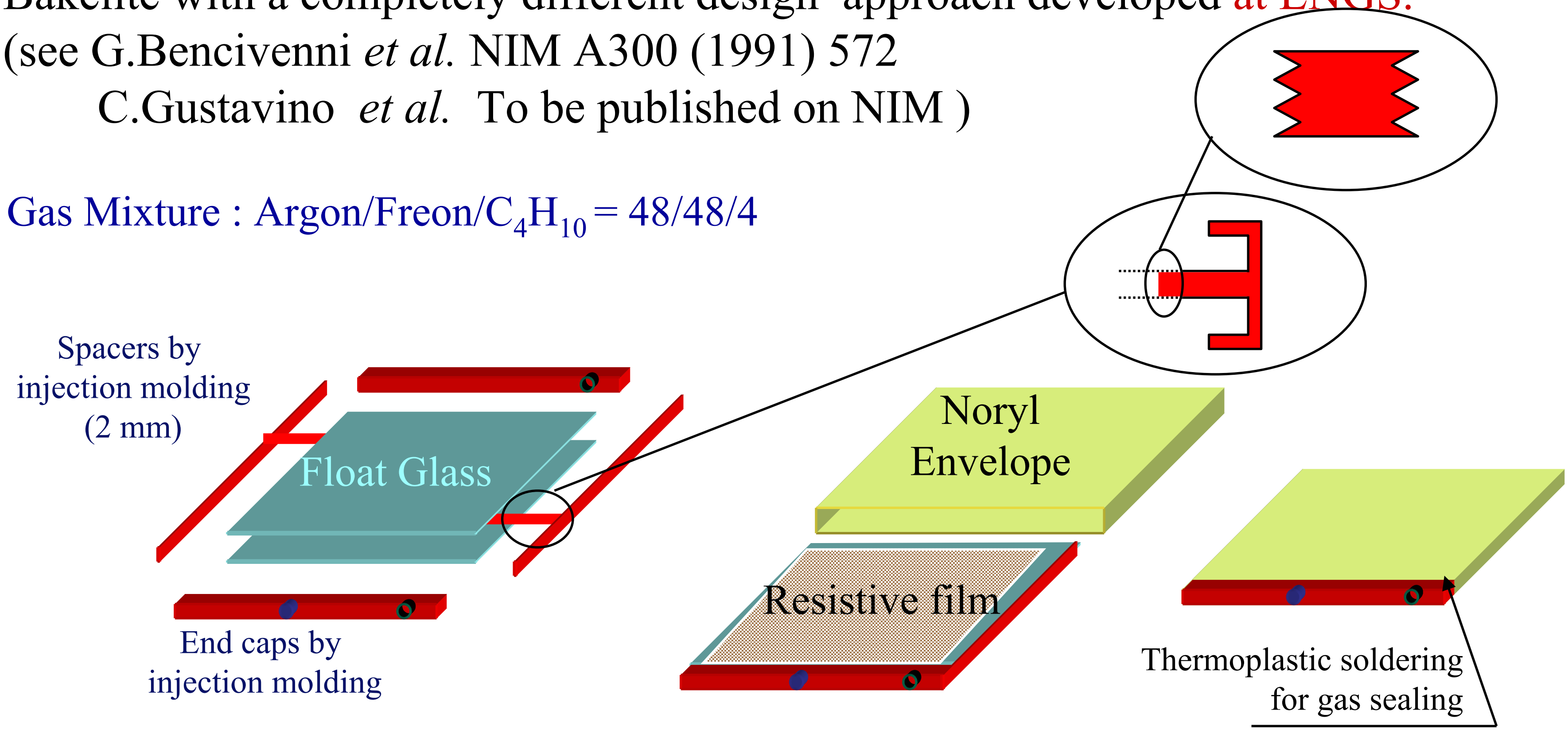


5 years of tests in Virginia Tech, 4 years operating experience in Belle

Glass Spark Counters (Monolith)

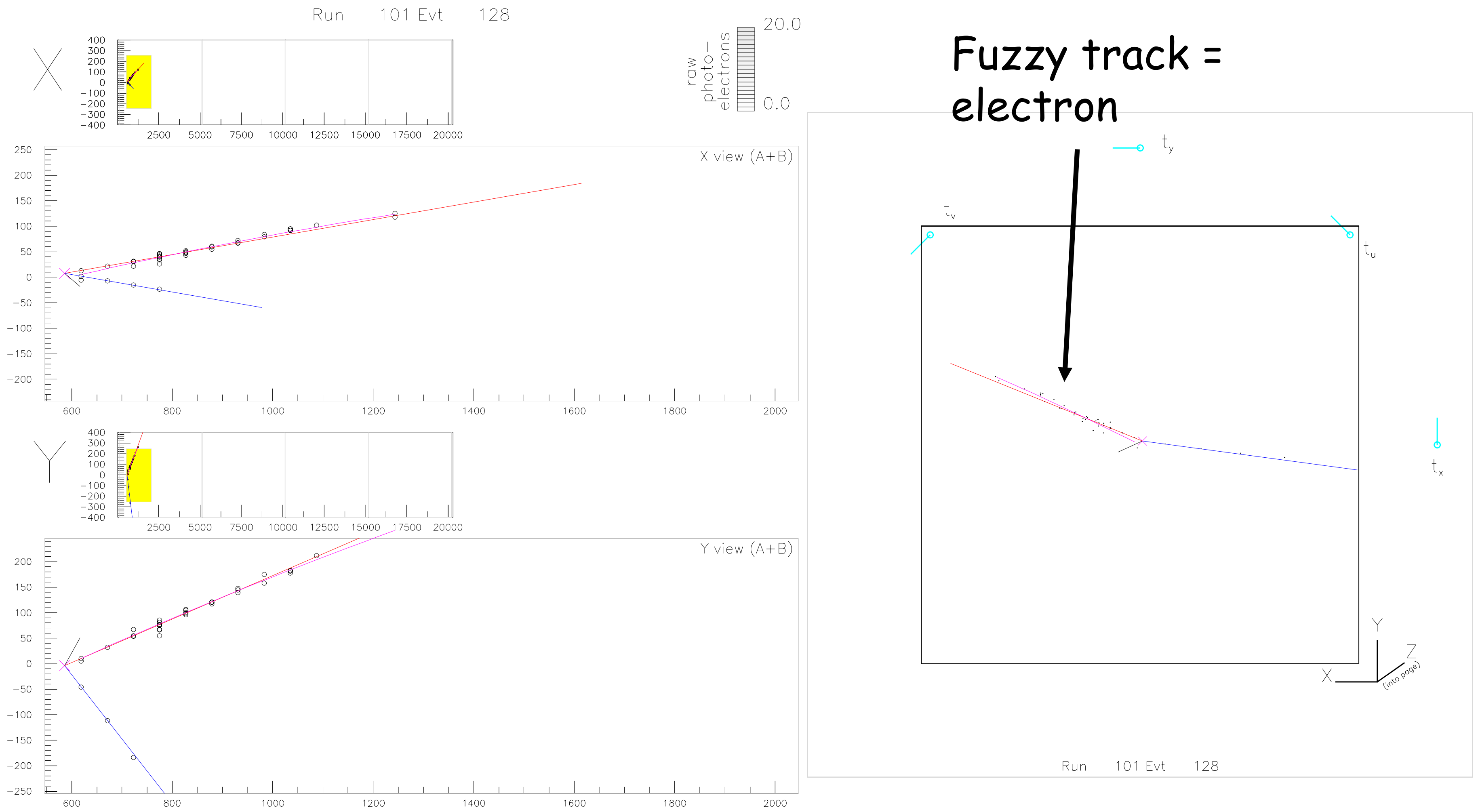
It is an RPC with electrodes made of standard float glass instead of Bakelite with a completely different design approach developed at LNGS.
(see G.Bencivenni *et al.* NIM A300 (1991) 572
C.Gustavino *et al.* To be published on NIM)

Gas Mixture : Argon/Freon/C_4H_{10} = 48/48/4



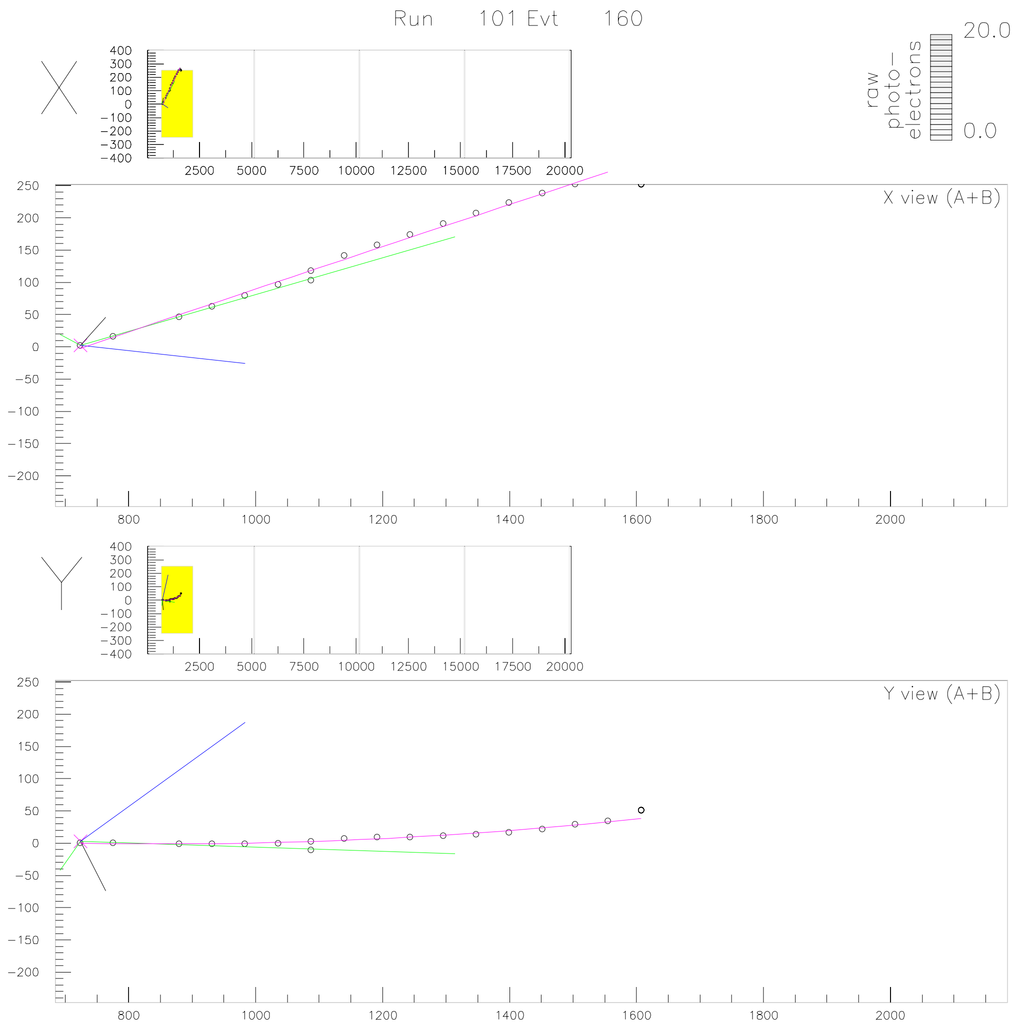
Easy and fast and cheap construction
Ready for mass production.

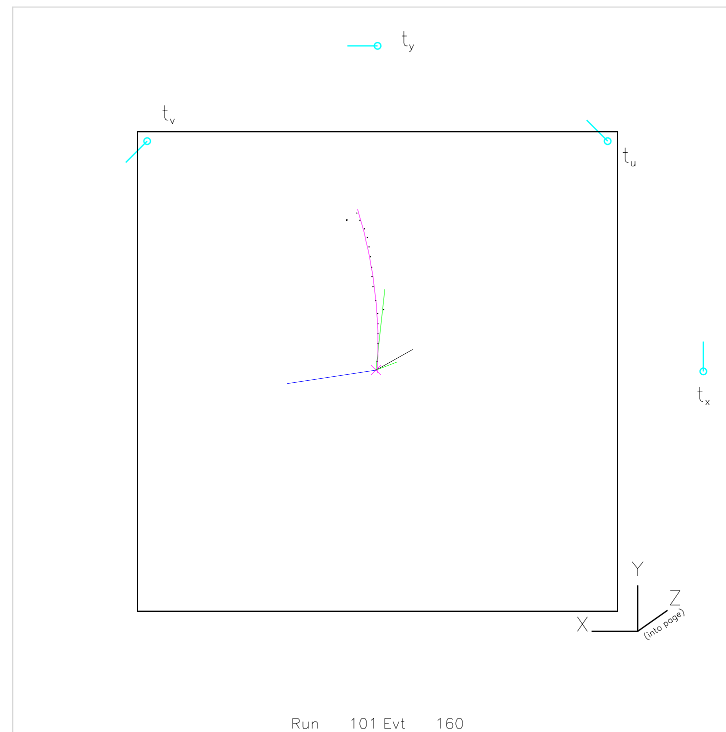
A 'typical' signal event



Fuzzy track = electron

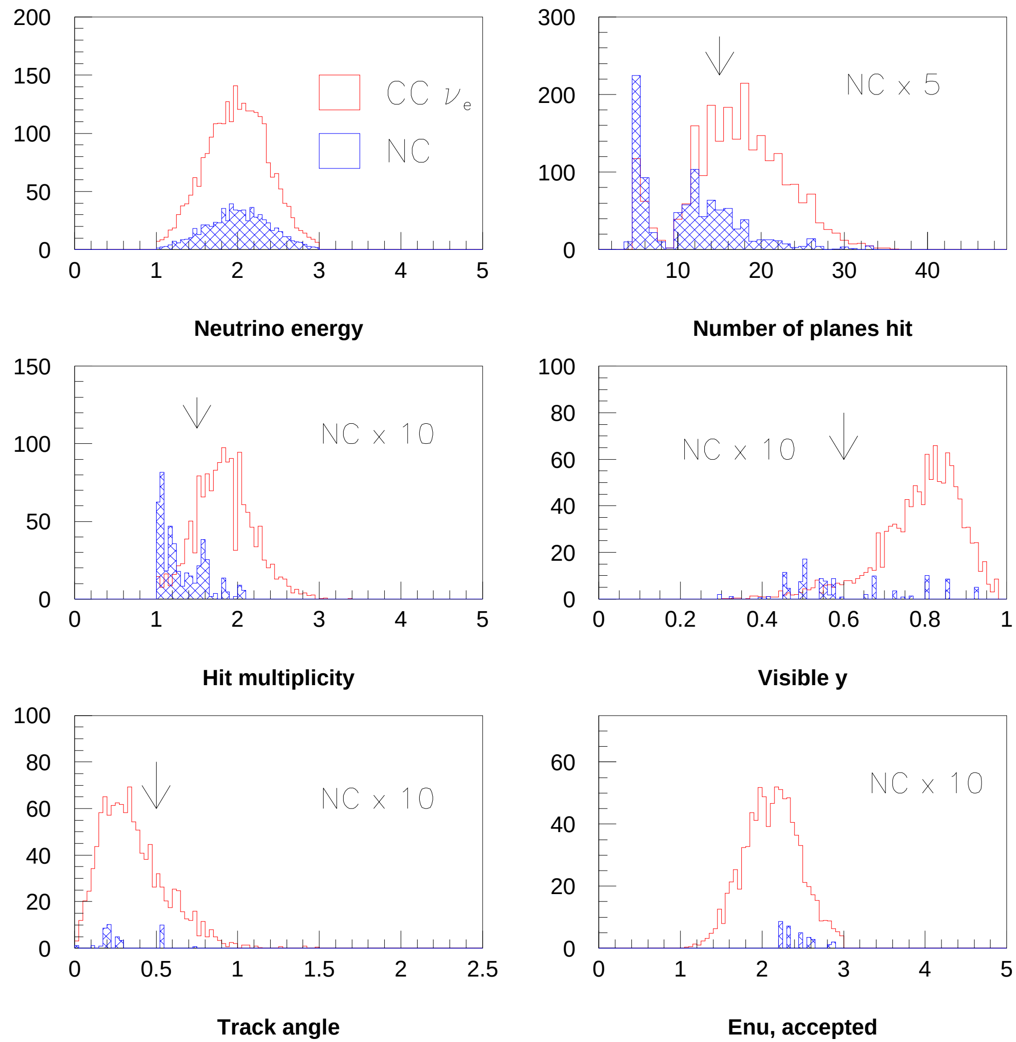
A ‘typical’ background event



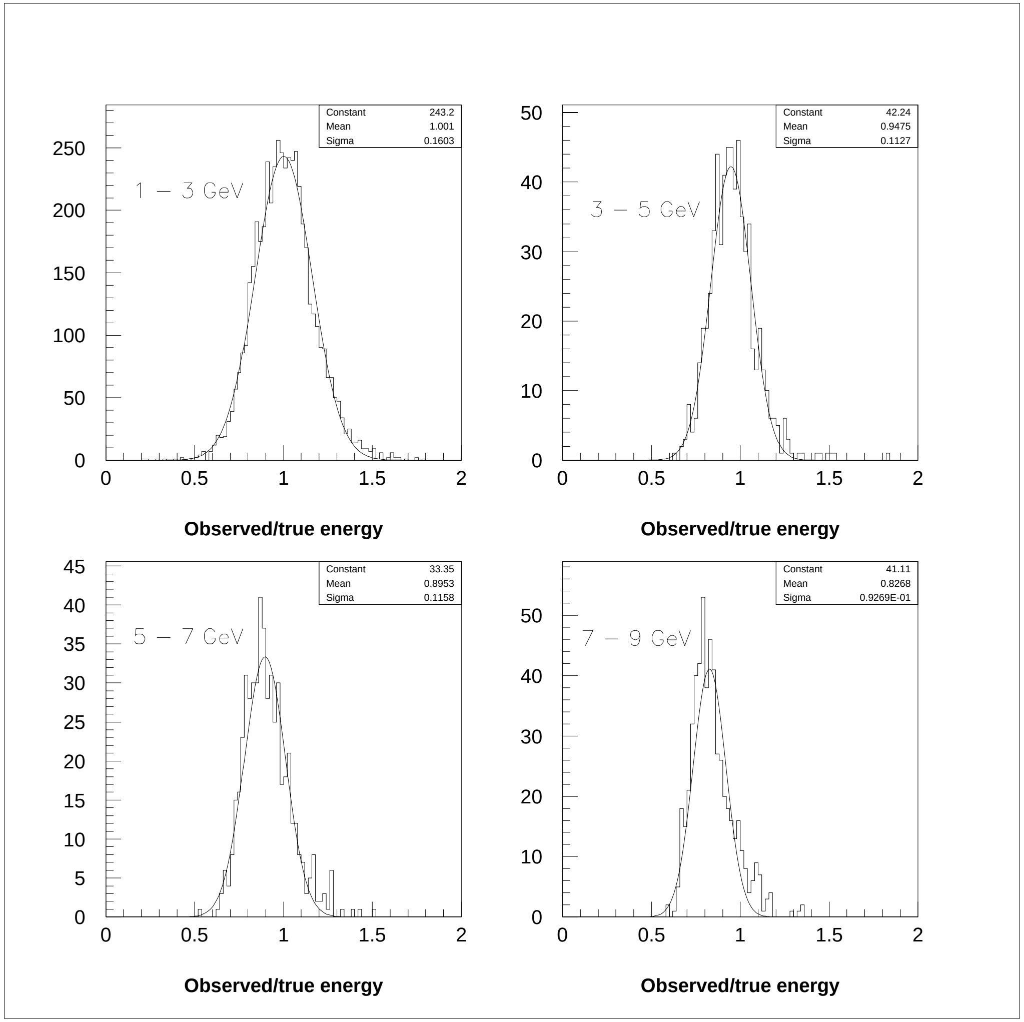


CC ν_e vs NC events in a tracking calorimeter: analysis example

- Electron candidate:
  - Long track
  - ‘showering’ I.e. multiple hits in a road around the track
  - Large fraction of the event energy
  - ‘Small’ angle w.r.t. beam
- NC background sample reduced to 0.3% of the final electron neutrino sample (for 100% oscillation probability)
- 35% efficiency for detection/identification of electron neutrinos

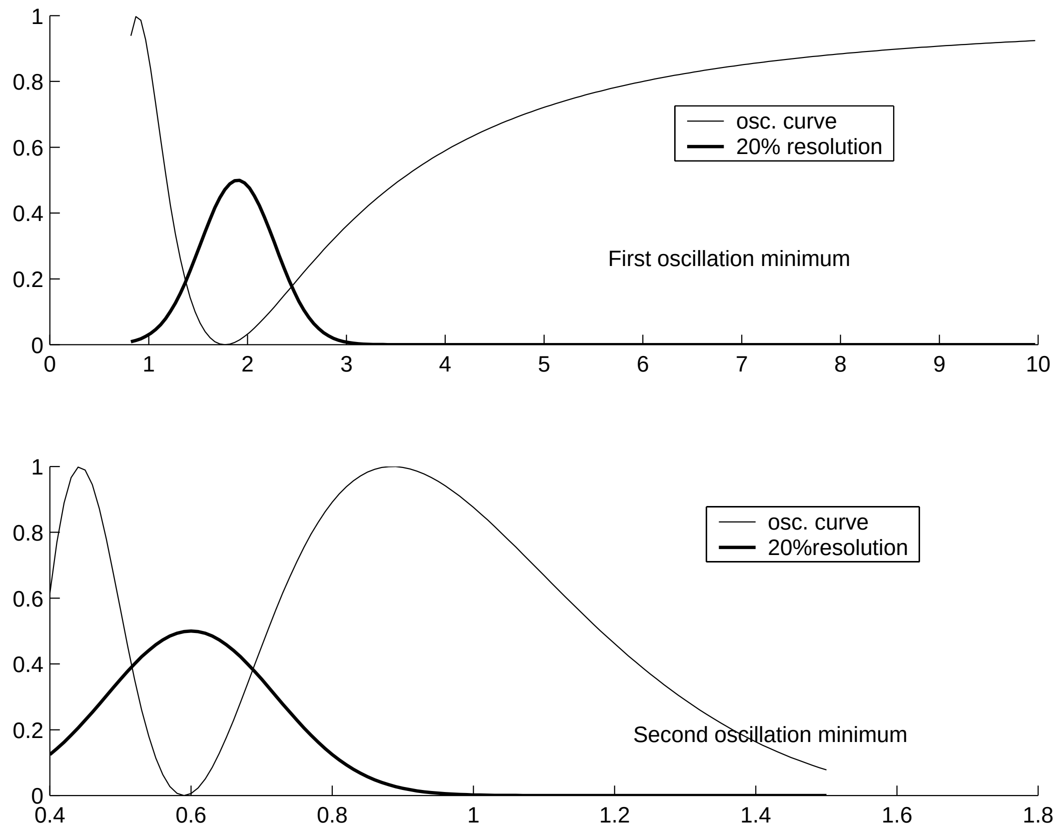


Energy Resolution of Digital Sampling Calorimeter



- Digital sampling calorimeter:
  - 1/3 X0 longitudinal
  - 3 cm transverse
- Energy = Cx(# of hits)
- DE ~ 15% @ 2 GeV
- DE ~ 10% 4-10 GeV
- ~15% non-linearity @ 8 GeV, no significant non-gaussian tails

Energy resolution vis-à-vis oscillation pattern



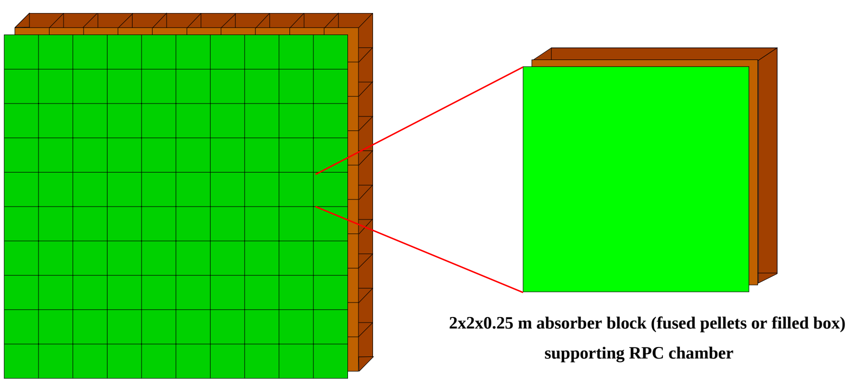
First oscillation minimum: energy resolution/beam spectrum ~ 20% well matched to the width of the structure

Second maximum: 20% beam width broader than the oscillation minimum, need energy resolution <10%. Tails??

Constructing the detector 'wall'

- Containment issue: need very large detector. Recall: K2K near detector – 1 kton mass, 25 tons fiducial, JHF proposal – 1 kton mass, 100 tons fiducial
- Engineering/assembly/practical issues

Absorber + detector wall stacked in a LEGO−like fashion from fundamental blocks



Solution: Containers ?

J. Cooper 5/3/02

Containers ?

- 90% of the world's manufactured goods (i.e. non-bulk) moves in standardized shipping containers
- **> 14 million units exist,**

  leading Ports handle 15 M units / year

  - **The most common types are: 20' Dry Freight** (x 8' x 8' 6")

    (6.1 m x 2.44 m x 2.59 m)

    40' High Cubes (x 8' x 9' 6 ")

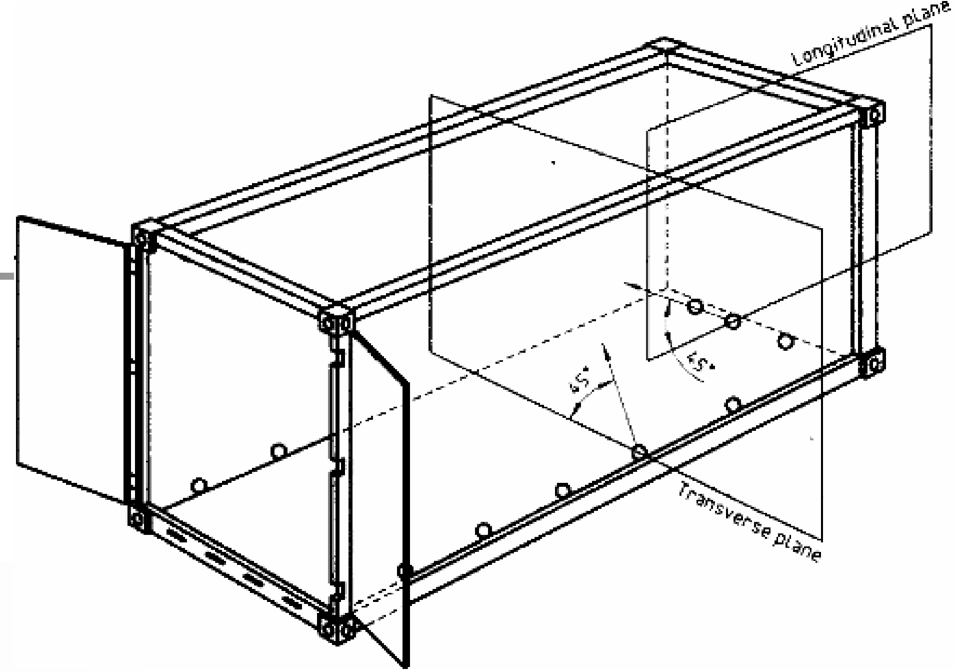
    (12.2 m x 2.44 m x 2.9 m)
  - **Jargon unit is the TEU**

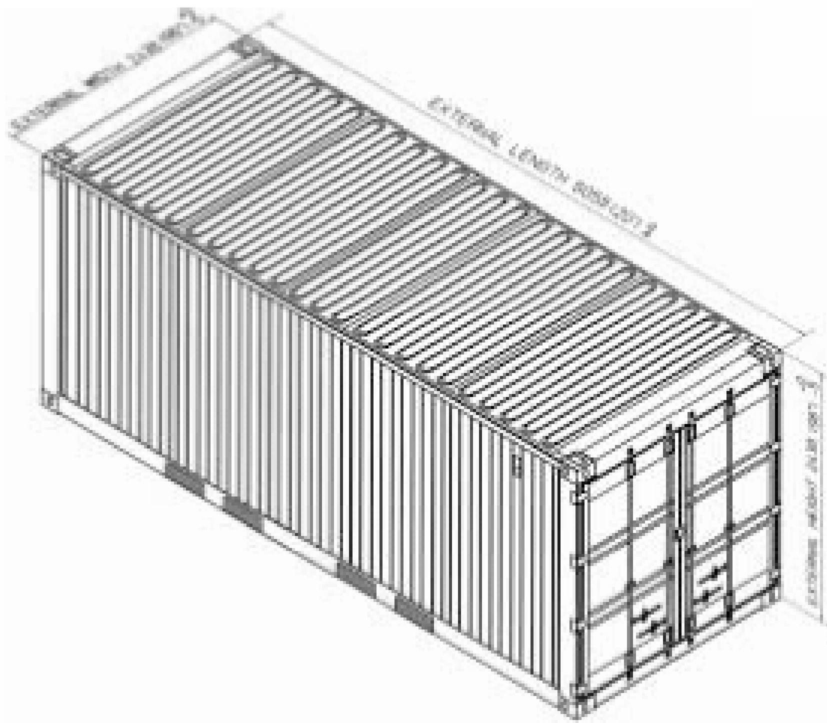
    (Twenty-foot Equivalent Unit)
- 1 million new TEUs built each year
  - This is real "mass production"

1 TEU

2 TEU – High Cube

Container Details

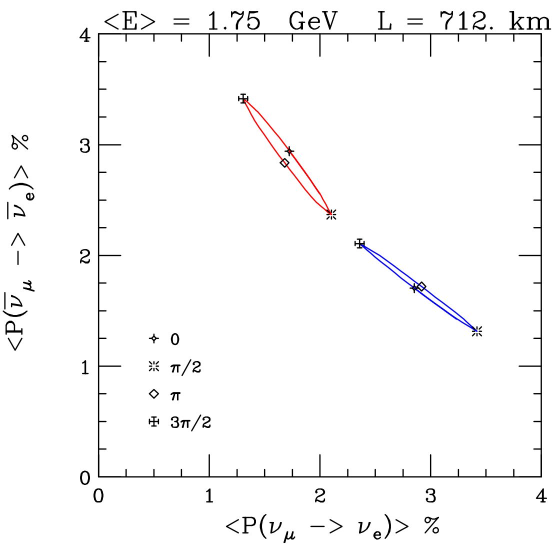


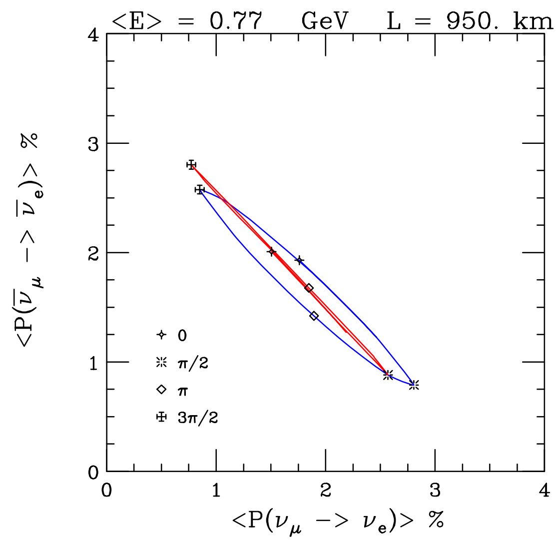


- <u>ISO specifications</u>
- Corner posts take load
- Corner blocks for rigging
- Corrugated steel sides & top
- Doors on one end (or more)
- Hardwood plywood floor sealed to sides
- Angle/channel steel support below floor, fork pockets

On the importance of being mobile: mammals vs dinosaurs?

$Sin^2 2\theta_{13}=0.05$





Super-superbeam somewhere? Here we come!

Detector Optimization Issues

- What is the optimal absorber material (mostly an engineering/cost question, if ΔX_0 kept constant)
- What longitudinal sampling (ΔX_0)?
- What is the desired density of the detector? (containment/engineering/transverse segmentation)
- Containment issues: fiducial volume vs total volume, engineering issues: what is the practical detector size?
- What is the detector technology (engineering/cost issue if transverse segmentation kept constant)
- What is the optimal transverse segmentation (e/π^0, saturation,…)
- Can a detector cope with cosmic ray background? What is the necessary timing resolution?

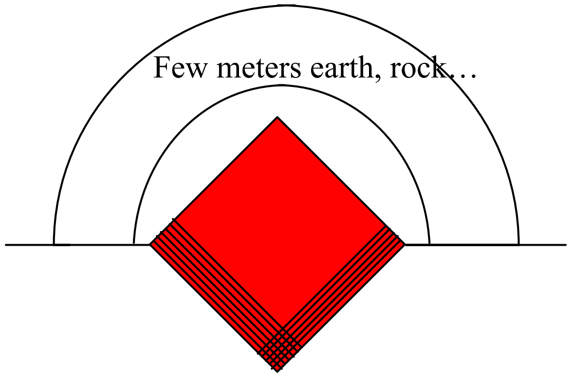
Backgrounds Summary

- ν_e component of the beam
  - Constrained by ν_μ interactions observed in the near MINOS detector (π)
  - Constrained by ν_μ interactions observed in the near MINOS detector (μ)
  - Constrained by pion production data (MIPP)
- NC events passing the final analysis cuts (π^0?)
  - Constrained by neutrino data from K2K near detector
  - Constrained by the measurement of EM 'objects' as a function of E_{had} in the dedicated near detector
- Cosmics
  - Cosmic muon induced 'stuff' overlapped with the beam-induced neutrino event
  - (undetected) cosmic muon induced which mimics the 2 GeV electron neutrino interaction in the direction from Fermilab within 10 μsec beam gate

• Expected to be very small

• Measured in a dedicated setup (under construction)

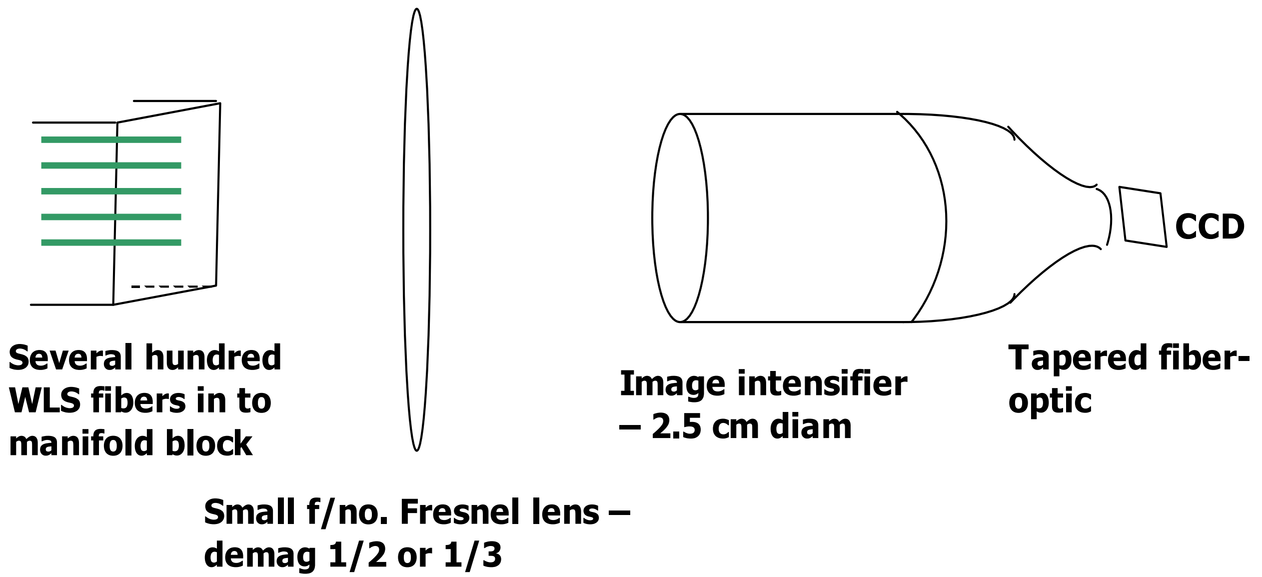
Liquid Detector Concept



- Cells of liquid scintillator ” 3 cm x 3 cm in 15 m (?) long multicell PVC extrusions
- 5 layers of water followed by a layer of scintillator

- Engineering was done for MINOS
  - Aging, strength of materials, etc.
  - Optical connections, manifolds, etc.
  - Fill method (after installation)
- Needs ~300,000 cells for 20 kT
- Challenge: readout for $10-20/cell?

A Possible Readout Scheme

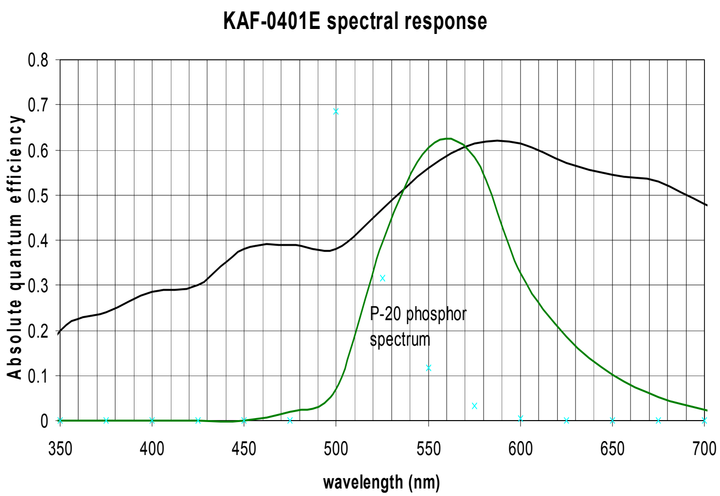


- Light emerges from fibers at angles < 47^o (calculated and measured) making lens coupler possible without excessive light loss
- Fresnel lens has diameter 15 cm, focal length 2.5 cm (3 coupled lenses each with f=7.5 cm)
- Can get 70% light from WLS at focus for demagnification of ½ - goes down rapidly beyond that

Image intensifier

- Cheapest from Litton who make zillions for military – “scientific” IIs from Hamamatsu, Photek, Proxitronic, DEP, etc, cost significantly more
- Generally much quicker delivery compared to “scientific” IIs – take from existing production lines
- Have bought a Gen-2 (1 MCP) 25 mm diameter (S-20 photocathode, P20 phosphor) - cost was $1990 – should go to $1500 for large quantities
- We are currently evaluating this device
- Have measured gain of 0.8×10^4 using light from WLS fiber
- Must connect to CCD via tapered fiber-optic for maximal light – phosphor light is ” isotropic (- taper costs $500 in large quantities!)

CCD



- CCD quantum efficiency ~50%
- ~$500 for Kodak KAF-0401E including components for electronic readout with pixel ganging
- 6.9 mm x 4.6 mm active area (9❍m pixels)

CCD read-noise

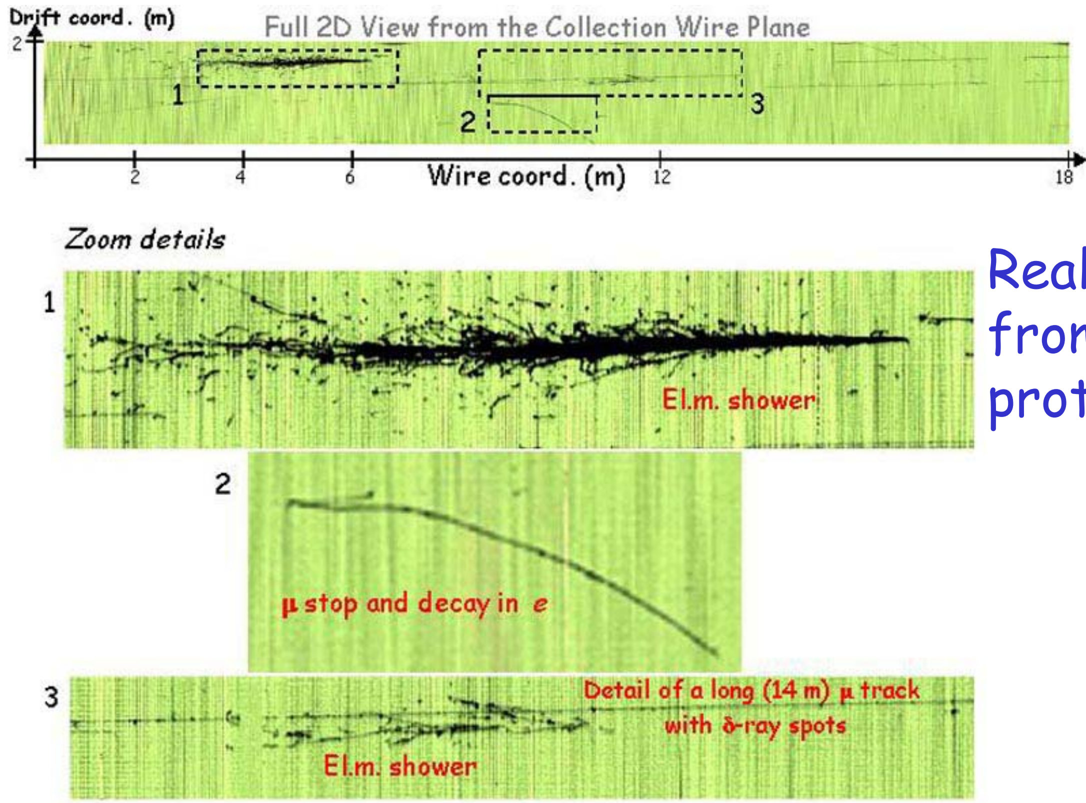
- Limiting feature
- Read-noise a few e/pixel from external amps, etc (- dark current is negligible in our gated operation)
- We have many pixels/fiber (CCD industry aims for best resolution – we need worst.
- Solution:
  - Gang pixels together to make bigger pixels – we have electronics to do this – being assembled now

The future

- We are currently evaluating light amplification/transmission through all components
- We are assembling CCD electronics
- Will have an operating ICCD camera in 1 month - see if we can see signal from MINOS scintillators
- Test liquid scintillator configurations
- Study simpler versions – e.g., fibers to manifold block ✸ Fresnel ✸ CCD (no II)
- We would like help, ideas……

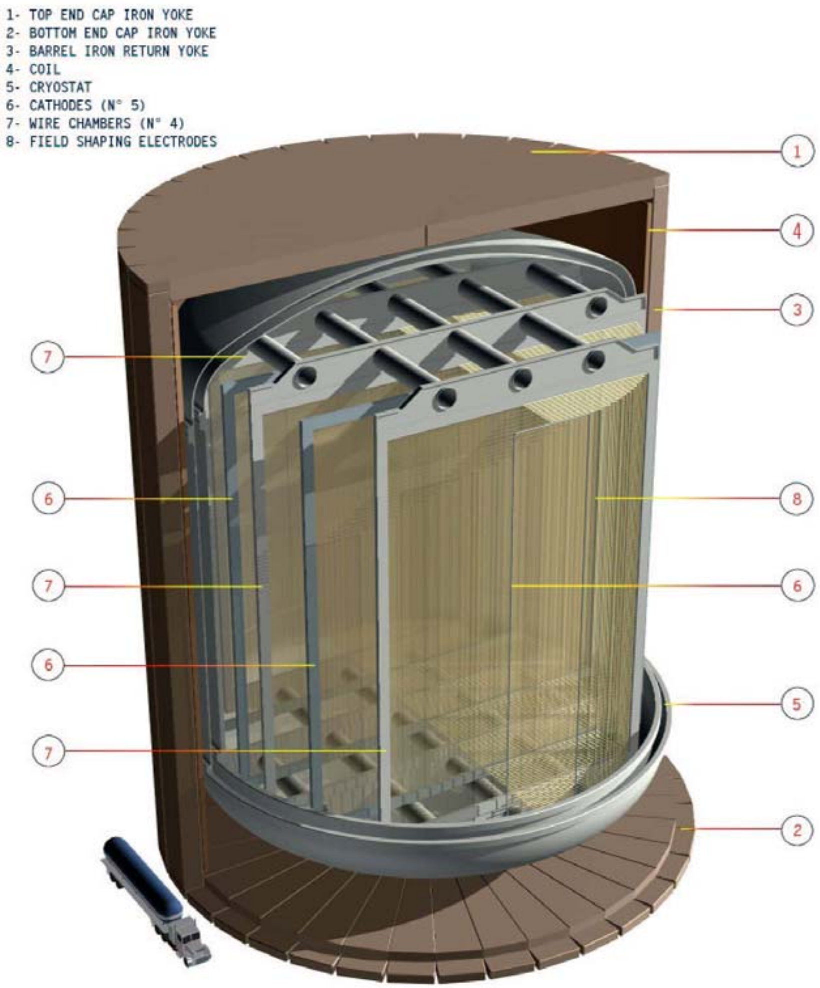
Liquid Argon : High Efficiency ν_e Detector

Electron/NC in complex higher energy events:
Imaging detector (Liquid Argon TPC)



Real data from 300 ton prototype

Liquid Argon TPC



LANNDD
Liquid Argon Neutrino and Nucleon Decay Detector

- Excellent pattern recognition capabilities
- High efficiency for electron identification
- Excellent e/π^0 rejection

Challenges of the Liquid Argon TPC

- Cost effective implementation
  - Single large cryostat
  - Argon purity in large volumes
  - Long drift distance
  - Very high voltage
- Safety, safety,safety
- Data acquisition
- A case of a dog, which did not bark (Conan Doyle)
  - 50 l prototype exposed to the WANF beam + NOMAD
  - 300 ton prototype exposed to cosmic rays in Pavia
  - No results (QE ν_μ? ν_e? Angular distribution of CR muons? Uniformity of the detector? Long term stability? Other?)

Small LAr TPC in a neutrino beam at KEK or Fermilab ? :

•Proof of principle as a reliable experimental technique

•Rich source of physics information about low E neutrino interactions

The Next Steps

- R&D effort on light Z detectors is ongoing
- Workshop on detector technology issues planned for January, 2003
- Proposal to DOE/NSF in early 2003 for support of R&D and subsequent construction of a Near Detector in NuMI beam to be taking data by early 2005 → Physics of low E neutrino interactions
- Proposal for construction of a 25 kt detector in late 2004